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THE INTEGRATION OF SHIP ELECTRICAL SERVICE POWER WITH SHIP ELECTRICAL PROPULSION POWER-A SECOND LOOK

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ASSOCIATION OF SCIENTISTS AND ENGINEERS OF
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THE INTEGRATION OF SHIP ELECTRICAL SERVICE POWER WITH SHIP ELECTRICAL PROPULSION POWER A SECOND LOOK

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The views expressed herein are the personal opinions of the author and not necessarily the official views of the Department of Defense or of a military department

LIST OF ILLUSTRATIONS

ABSTRACT

The previous paper on the subject was reexamined and brought up to date in application to new ship designs. Further advantages of the system are discussed. Criticisms of the system are answered. The application of energy recovery systems is included.

THE INTEGRATION OF SHIP ELECTRICAL SERVICE
POWER WITH SHIP ELECTRICAL PROPULSION POWER -
A SECOND LOOK

D. S. Toffolo

January 1982

The subject of this paper was first presented by the author of the ASE at the 15th Annual Technical Symposium in 1978. The salient points of that first look delineated the advantages of the electrical propulsion system of a gas turbine propulsion ship. They are listed here for convenience.

a. Prime movers can be located to reduce the amount of expensive "real estate" used by the gas turbine ducts, at the same time making it easier to replace the gas turbine engines than present practice on the USS SPRUANCE (DD 963) Class destroyers.

b. The electrical propulsion power transmission system allows a variable speed ratio between the prime movers and the propellers which can be used to increase the efficiency of the prime movers.

c. Long runs of line shafts are reduced.

d. A fixed pitch propeller which is more efficient and reliable than the controllable pitch propeller can be used.

e. The total power plant (for ships with more than one propeller) can be used in a variety of configurations in order to operate all shafts with minimum fuel usage and maximum engine operating life at any power level desired.

f. Failure of a gas or steam turbine only reduces the total power available; the propulsion power transmission system allows the remaining power to be equally distributed between all propellers.

g. Ship designs involving odd numbers of installed gas or steam turbines are practical.

In addition, other advantages were claimed for the integrated electrical propulsion and electrical ship service plant as follows:

(1) Greater fuel economy by a factor of 2, than can be gained as claimed for a separate electrical propulsion system (unintegrated) compared to a mechanical system. This applies to ships using gas turbines for prime mover power of the electrical ship service generators.

(2) A probable reduction in acquisitional, operational, and maintenance costs with a potential increase in reliability (due to fewer components).

(3) Potentially better ship service electrical power due to greater frequency stability and greater voltage stability with less transient voltage (due to pulsed loads) disturbances.

(4) Decreased acoustic signature.

(5) Volume made available for weapons space assignment as smaller machinery spaces will be required.

(6) Some reduction in manning requirements.

Since the time of that first presentation many studies have been made, both in-house and by outside knowledgeable contractors, which have substantiated the above in large measure. Thus, it would appear that the selection of a propulsion plant for a new ship design would be a relatively simple matter were it not for the risk factor. The choice could be the integrated electrical propulsion and electrical ship service plant, particularly where an odd number of prime movers for propulsion are required or specified. This latter constraint can be (and has been) imposed whenever the listing of available propulsion prime movers is limited to those engines which have seen service use in the Navy or certain power levels are desired or necessary. Only operation at a LBTS of such a plant would yield a realistic conclusion.

From the studies done on proposed surface combatants, there is more to the selection of a propulsion plant than just the consideration of its advantageous characteristics. The proponents of mechanical propulsion have exhibited ingenuity in the adaptation of mechanical propulsion to new ship designs, such that many of the comparative advantages claimed for electrical propulsion have been invalidated. The invalidation was done by new and novel mechanical propulsion designs but at the cost of added risk over present mechanical designs. Ship layout arrangements can also cause a highly advantageous propulsion system to have a negative impact upon the ship as a whole.

Focussing on the evolution of integrated electrical plant concepts from the time of the first presentation to the ASE, the characteristics of the integrated electrical plant which will always differ from those of the mechanical plant are:

a. The prime movers for the integrated electrical plant can be used to provide either electrical propulsion power or electrical ship service power and at times instantaneously demanded electrical service power with negligible frequency change. The mechanical propulsion plant dedicates prime movers to provide propulsion power or ship electrical service power on a mutually exclusive basis. It is for this reason, together with advantages e and f above, that the electrical plant has been said to have a graceful plant degradation upon casualty loss of any prime mover.

b. The number of prime movers for the electrical plant will normally be less than those required for the mechanical plant primarily because a single prime mover will provide both propulsion power and ship service power.

c. The addition of Rankine cycle energy recovery systems to the integrated electrical plant can provide both (simultaneously or either) electrical propulsion power and electrical ship service power; whereas, for the mechanical plant, RACER can only provide one or the other. In fact, for most practicable ship designs RACER can only provide propulsion power. Waste heat recovery other than RACER can be applied to electrical ship service generation in the integrated electrical system just as well as in the mechanical propulsion ship.

The particular evolution of the integrated electrical plant to be next described is one that in large measure occurred in studying various options for a two shaft 72,000 hp ship. After a feasibility study by three outside vendors had been completed, the author believed that the optimum integrated electrical plant for such a ship would contain five prime movers. These prime movers would include a mixture of gas turbines and diesel engines and the problem was to evolve the optimum set. Diesel engines were almost mandated for inclusion onboard by the mission profile of short times at high speed and by the "at anchor" requirements where considerable time is spent providing electrical power at rather low levels (relative to the propulsion power), such as 3.5 MW.

One can consider various combinations of gas turbine and diesel prime movers; a five-gas turbine integrated plant as shown in figure 1, a four-gas turbine plant (with one diesel) as shown in figure 2, a three-gas turbine plant (with two diesels) as shown in figure 3, or even a two-gas turbine plant (with three diesels) as shown in figure 4. All these options have the same propulsion motors. These propulsion motors, even though water-cooled, are rather large because of their relatively low speed when direct-driving the propeller. They can be eliminated by using high-speed synchronous machines in a hybrid plant arrangement as shown in figure 5 for the five-gas turbine plant and in figure 6 for the two-gas turbine plant. These arrangements are all of the COGAG or CODAG variety. Figure 7 shows what the hardware for the integrated plant module, propulsion generator, ship service generator and gas turbine, looks like.

Each one of these options would be differently arranged by naval architects in their own hull and each different hull would have a different speed-power curve. Consequently, each option would have a different annual fuel consumption over the mission profile, a different endurance fuel and a different top speed and top speed endurance. The acquisition and maintenance costs would differ. The reliability and survivability would differ. When these and other factors, established as evaluation criteria were taken into account, an integrated electrical propulsion candidate emerged. The candidate that emerged from the in-house studies was the same as that which finally emerged in the conceptual design of an integrated electrical system by a private contractor. The latter used his own selection criteria which differed somewhat from those used by the Navy in the in-house studies. When the difference in selection criteria was reconciled, the difference in candidates disappeared.

The mechanical propulsion plant also evolved so that one needs to relate that statements in paragraphs e, f, and g above are true for the mechanical propulsion plants.

Statement (1) above, concerning fuel economy, was only true in the previous paper, because gas turbines (Allison 501-K17) were used to power the ship electrical service generators. The statement is not true for those options which employ one or more diesels to generate ship electrical power.

Statement (2) above applied solely to the comparison for the SPRUANCE Class destroyers. When comparing integrated electrical propulsion options to mechanical propulsion options, there are a variety of conclusions so that this criterion is no longer meaningful.

The third statement about better ship service electrical power, etc., needs expounding here particularly because the general feeling among some (but not all) electrical system engineers was that the quality of the electrical service power would not be as good as that provided by separate ship service diesel generator sets such as on the mechanical propulsion ship.

Several problems were raised and the author wishes to present a resolution of each one.

The first was that maneuvering of the ship would cause a frequency disturbance on the ship service electrical bus. The contractor doing the conceptual design was specifically tasked to address this and other problems by means of a computer simulation study of the phenomenon. The preliminary study showed that transient limits set by applicable standards would not be exceeded in crash astern, propulsion bus faults (symmetrical or asymmetrical), harbor maneuvering and high speed turns. The main reason for this specification performance is that the motors can be controlled independently in various ways, constant speed, constant power or constant torque. In the constant power mode, for instance, with the propellers coming partially out of the water due to heavy seas, no change in the propulsion power gas turbine speed occurs and no change in throttle setting is necessary. The only thing that happens is that the propeller speed changes as it comes out of and goes back into the water, albeit in consonance with constant shaft power (not RPM) output. There is some measurable turbine speed deviation but it is in the order of 1 percent.

The study also showed that there is no ship electrial power system instability induced by the maneuvering commands. The maneuvering commands are always ramped in such a manner that propulsion power changes do not occur faster than the time constant of the engine governor allows. The ship electrical service generators have synchronizing torque between them whereas the propulsion generators and the frequency changers do not. This allows the phase of the terminal voltage of the propulsion generator to shift with respect to its excitation voltage phase. The latter excitation voltage phase is tied (in time) to the phases of the excitation voltage of the ship electrical service generators because of the mechanical locking by the gearbox of the field poles of the integrated electrical generators. As the power angle of the propulsion generator changes, the phase of the terminal voltage of the propulsion generator shifts, not the phase of the excitation voltage. As a consequence, the phase of the terminal voltage of the ship electrical service generators is not affected. They are operating at a constant power angle with a fixed phase reference excitation voltage.

In passing, one can state the mechanical propulsion plant, be it mechanically or electrically cross connected, cannot adjust the power to each propeller as can the integrated electrical plant unless for the electrically cross connected a frequency changer is used. A second consideration along these lines is that the mechanical plant, mechanically or electrically cross connected, will always have the propellers in exact synchronism. What hull vibrational problems or increased acoustic signature are engendered by this condition are unknown at this time. This matter should certainly be studied and analyzed by those who propose mechanically cross connected propulsion plants. This synchronism is not true of the integrated electrical plant where each motor is individually driven and can be deliberately made to differ in speed by as small a delta as desired.

The last problem involves the availability of the circuit breakers required to be incorporated into the electrical ship service system of the integrated plant. The problem arose because of the larger than previously used ship electrical service generators. Given the present schedule for delivery to a land-based engineering facility, one can say that by means of generator design or bus design further development work in circuit breakers may be unnecessary. Circuit breaker development work will be undertaken, however, not only with the objective of reducing the weight and volume of currently available breakers and improving their shock closure properties but also to increase their current capability. The point being made here is that procurement of satisfactory circuit breakers is not on the critical path to the establishment of the integrated electrical propulsion plant at a land-based engineering facility.

Having said all that, it still remains to be said why the third statement is true in a clearly understood fashion.

The integrated electrical plant option employs larger electrical ship service generators than those employed in the mechanical propulsion plant ship option. As a consequence, any large load that is connected, for instance a large induction motor, will necessarily cause less of a voltage transient to occur on the integrated electrical plant option because of the larger generating capacity to which it is being connected, ceteris paribus. This same large induction motor instantaneous load application will cause less of a frequency transient on the integrated electrical plant option for two reasons. One, the inertia of the integrated electrical plant includes not only the ship service electrical rotating machinery but also the electrical rotating propulsion machinery. Hence, the total inertia is much larger than the inertia of the electrical ship service generating plant utilized in the mechanical propulsion ship option. This inherently makes for a smaller frequency transient. Two, the shaft power of the propulsion engine can be one half cycle wise (of 60 Hz) applied to the electrical ship service generator with a consequent reduction in propulsion power which will hardly be noticeable due to the ship dynamics. The transient frequency excursions can be made negligible. Such a condition has not been nor will be observed on any electrical power system today or for some time in the future onboard ships of the Navy. The condition will appear when integrated electrical plants are operating in Navy ships. The author takes special pains to point this out as he has been dismayed by the notion, of which he has been recently made aware, that the integrated electrical propulsion and ship electrical service system is deemed by many electrical system engineers to have inferior frequency characteristics to those of present ship electrical service systems.

One can go even further and say the integrated plant has an additional potential capability which is not generally recognized and for many is entirely unknown. Navy generators by specification can deliver 150 percent power for 2 minutes. However, this capability is little used on Navy ships for the simple reason that most engine generator sets do not have the capability in the engine to provide 150 percent real power. This is especially true of diesel or gas turbine generator sets. In the integrated electric plant such engine power is available from the propulsion engine, of course with a concomitant reduction in propulsion power. This reduction in propulsion power is in accordance with electrical system guidelines which have established a hierarchy of power wherein the electrical system has the highest electrical power priority. To retain the integrity of the weapons system, all available prime mover (and more is available in the integrated electrical plant) power must be applied to the electrical ship service generators. The Captain of the ship may use the available electric power as he sees fit.

With the present projection of battle loads for future ships and with suitable options exercised for excitation power, one electrical ship service generator in the integrated electrical plant could provide the entire electrical battle load for 2 minutes without load shedding of any kind. The author believes this potential capability should be taken into account when assessing relative merits of propulsion plants, for this potential capability does not exist for the mechanical propulsion ship option.

The next topic which the author wishes to discuss is the application of Rankine cycle energy recovery systems. While the application of RACER to integrated electrical plants can be used to provide electrical propulsion or ship service power, the exact division of the power should be a relative matter; relative to the electrical propulsion level and to the electrical ship service level. These two levels never stand in the same ratio, and it is precisely because of this situation that the division of the recovered energy should also be variable as necessary. This variableness gives the integrated electrical plant the potential to maximize the utility (i.e., decrease the fuel consumption) of the energy recovery system while improving the combat capability. This latter improvement will occur because of the increased frequency stability that will occur because of the increased frequency stability that will accompany the RACER adaptation.

The RACER application has thus far not been as thoroughly studied as other non-RACER options. It is entirely possible that when a thorough analysis is done for RACER options, new candidates for integrated electrical plants may emerge such that the minimum number of prime movers (exclusive of those utilizing the recovered energy) will change. One such option is shown in figure 8. This is an all gas turbine arrangement which would have ASW advantages as does any all gas turbine ship.

A recent study initiated by the Navy undertakes to develop a propulsion plant (electrical or mechanical) and an electrical ship service plant for a twin screw ship. The estimated shaft horsepower is 70,000 in one version and 50,000 in a reduced version; both shaft powers would give their respective ships a top speed of 30 kn at 160 propeller RPM. The electrical ship service load is estimated to be 13,800 kW with suitable margin. An additional requirement specifies the prime movers to be all gas turbines with the stipulation that RACER may be employed to supply a steam turbine. The energy recovery would take place in the exhaust stack of the appropriate gas turbines using a heat exchanger boiler.

By the experience gained from previous studies, a principal conclusion of the author is that RACER utilization should be applied only to the cruise engines. From the knowledge of the size of the motor for a 35,000 hp shaft, it is doubtful that a direct drive 70,000 hp electric motor and the two 18 MW generators to power the motor would be cost effective or volume efficient for a 70,000 or 50,000 hp shaft. The attractiveness of the hybrid plant, such as shown in figure 5 suggests that a hybrid option have a priority consideration.

A first cut at an integrated electric plant hybrid propulsion plant, using as much hardware as possible that is in current use by the Navy, is a relatively simple effort. The extensive effort expended to produce the first conceptual electrical integrated plant provided the means for simplifying the present effort. Three basic modules are formed, interfacing with each other to become the total integrated system, hybrid propulsion and ship service power.

The three are:

(1) The propulsion and boost module, shown in figure 9 and figure 10, one for the starbord shaft and the other for the port shaft. Because the two propellers must be rotating in opposite directions and because the gas turbines as procured rotate in one direction only, the gearbox and gas turbines are inverted from one side of the ship to the other. Each boost turbine is rated at 24,500 hp and will be used only in the boost ship operational modes 22 kn or higher speed. Up to and including 21 kn all the propulsion power is provided by the synchronous water cooled motor of 24,000 hp capacity at 112 RPM. For this module, the gas turbine is the LM2500 and the gearbox is that used on the 963 SPRUANCE Class destroyers. The motor is a new element not in use by the Navy but it is a design component which does not need development. A new thrust bearing will also be required but that too is a design component. No CRP will be required, a fixed pitch propeller will be used. The synchronous motor provides sufficient torque for braking the propeller to zero RPM and reversing its direction of rotation to stop the ship dead in the water for a crash astern maneuver. The two synchronous motors will also propel the ship at 21 kn in the astern direction. For a direct drive electric plant option, a motor twice the size of that used in our propulsion-boost module would be necessary, two propulsion 18 MW generators would be coupled, one to each boost turbine but the gearbox would be eliminated. The net gain in weight saving and volume saving favors the hybrid propulsion-boost module described above, one gearbox compared to one motor and two generators. A detailed study would be necessary for a final evaluation.

(2) The integrated propulsion and ship service module, shown in figure 11. This module has the LM2500 gas turbine, the RACER steam turbine and the two generators, one for propulsion - the 18 MW cruise generator and one for electrical ship service - the 8 MW generator. The LM2500 is in use by the Navy; the 8 MW ship service generator is taken from the CVN Class and is a 3600 RPM generator at 4160V. Transformers for the ship service 450V system are used as in the CVN Class. The cruise generator and the freqency changers

to power the cruise propulsion motor are design components. The combining gearbox is also a design component. For this module only the LM2500 and the 8 MW ship service generator are in current Navy use.

(3) The standby electrical ship service module, shown in figure 12. Here a single generator is shown powered by two gas turbines. The 8 MW generator is the same as that used in the integrated module (2) and is in current use. No single gas turbine of 10,750 hp is currently available; none is in use in the Navy. However, the electrical ship service power requirement is 13,800 kW. The two generators, one each on the two required integrated modules, will provide 6900 kW individually. With the 10 percent system operational margin, the standby prime mover power required is 7590 kW. The LM2500 engine has a rating of 4700 hp and is currently being tested to establish its transient capability. Two of these engines are shown tandem coupled to the generator in figure 12. They could power the 8 MW generator to provide 7000 kW of power. This appears satisfactory for the initial ship use when the provided power margin is not used. A second consideration is that this engine is under constant improvement by the manufacturer. By the time frame envisioned for this ship, the engine could be rated at 5000 hp when procured for use and have suitable transient performance characteristics. In any event, two such modules can be installed which should be satisfactory.

Putting all this together, the entire integrated electric hybrid propulson plant is shown in figure 3. The normal operation up to cruise speed is to light off the LM2500 gas turbine which supplies steam to the RACER turbine and together they provide 32,500 hp for the two generators in the integrated module. At 21 kn, the frequency changers take 17,900 kW of power from the cruise generator; the remaining power of the two turbines, 6300 kW, is then available to the ship service generator. This use of the RACER turbine in the integrated module is one advantage the integrated plant has over the straight mechanical plant. The power from the RACER steam turbine can be used either for propulsion power or for electric ship service power or in power supply concomitance. The motor powers the propeller up to 21 kn ship speed. At that point, when and if further increases in speed are commanded, one or both of the boost gas turbines are lit off and each adds to the torque on the propeller shaft. The frequency changers can keep the motor at constant 24,000 hp output for all ship speeds from 21 kn to 30 kn.

Several emergency modes are worth discussing. Suppose an integrated module LM2500 gas turbine goes out in the cruise mode at 21 kn. One of the boost LM2500's can be lit off to provide 16,000 hp propulsion power. The remaining 8000 hp is transmitted by the motor (acting as a generator) through the frequency changers to the cruise generator on the integrated module. This generator will now be performing as a motor, turning the gears to supply power to the ship service generator on the integrated module. The speed of the ship will be reduced to 19.75 kn. If this not tolerable, the boost engine is lit off to supply 24,000 hp to the shaft and the standby module is started up (two LM2500s) to supply 7000 kW of electric ship service power. The integrated module will be secured. The speed of the ship will remain at 21 kn. In a perceived emergency situation of short duration, 2 hours or so, the standby modules, or module as the case may be, are started up. The 8 MW generators can be paralleled with the cruise generators on the integrated module and provide 8000 hp more for propulsion. Both the frequency changers and the motor can be designed to take this overload (33 percent) for the period of time estimated above. This will boost the ship speed up to 31.1 kn based on a cubic propeller law. These are examples of the kinds of things that can be done, if desired, and are indicative of the flexibility of an integrated electric hybrid propulsion plant.

For the 50,000 hp per shaft ship version, only the propulsion-boost module need be modified. One of the boost LM2500 gas turbines is removed. The direct drive motor is also removed and a 3600 RPM synchronous motor is coupled to the gearbox in place of the removed LM2500. The module then appears as shown in figure 13. This ship version will attain a higher cruising speed before requiring a boost engine light off. The top cruise speed, with the integrated gas turbine plus the RACER turbine in operation, would be 23.5 kn.

One last topic is presented for the reader's contemplation. That topic is the utilization on Navy ships of directed energy weapons systems. These will include high energy lasers, charged particle beams and high power microwaves. The weapons systems are in various stages of research and development. "In general, a directed energy weapon consists of a device to generate the electromagnetic energy or accelerate the particles and a subsystem to track the target and direct the energy to a selected aim point." The quotation is from the enclosure to NAVSEA Instruction 5400.38A, dated 17 November 1981, promulgated by the Commander, VADM E. B. Fowler.

Where is the Navy going to get the electrical power required for these devices which generate the EM energy or accelerate particles, particularly when the average power (for multi-megawatt pulse weapons) will probably be in the 50,000 to 100,000 kW range? The author suggests that hybrid propulsion plants such as the propulsion-boost module be considered. For the 70,000 hp per shaft ship version, one could (hopefully) modify the 963 SPRUANCE Class gearbox by extending a shaft from the turbine pinion through the gearbox casing, duly modified, with a coupling on the end of the shaft to connect on an 18 MW generator. This will give us a total of four such generators for the ship under study. These generators will provide 72,000 kW of power for the new directed energy weapons system. Thus, if this ship now being studied were to be constructed, it could, or at least it should, be constructed in such a way that modified gearboxes could be installed together with the four generators. The modification could take place at some future date when the directed energy weapons systems are available for ship installation. The point is that ships which are built having the integrated electric hybrid propulson plants in them could provide the most cost effective platforms, not to mention having the shortest conversion times to combat readiness, than other ships in the fleet chosen for conversion.

Unless the Navy begins (and it may have begun even though the author is not aware of any such beginning) to make some provision for the electric power source for these weapons systems, a situaton may arise where the weapons system (devices) may be available before the required electrical power sources are available or even worse, no suitable platform for conversion exists. In that event, a new ship design to take these weapon systems could require as much as five more years to construct after the weapon system is available.

The present 70,000 hp per shaft ship version delineated above could provide 50,000 kW of weapons power while steaming at 26.45 kn without any conversion. The operating mode would be two boost gas turbines on the propulsion-boost module providing the propulsion power. The integrated module would take the 18 MW from the cruise generator and supply it to the weapons systems. Two of these generators (figure 13) supply 36 MW. With both standby modules started up 14 MW more are available (7 MW from each module) for a total of 50,000 MW as claimed.

Weapons system selection has had little or no impact upon the propulsion system up to now. It should be apparent from what has been said above that directed energy weapon systems could have a considerable impact upon propulsion systems and indeed, may have a decisive impact.

In retrospect, I was happy to have presented my original paper to this Symposium in 1978 and I am happy to present this "Second Look" today. The events that have occurred since the first look have given me confidence that the concept of an integrated electrical propulsion and electrical ship service power system could be a viable alternate to existing propulsion and electrical ship service systems onboard our present Navy ships.

POWER FLOW DIAGRAM

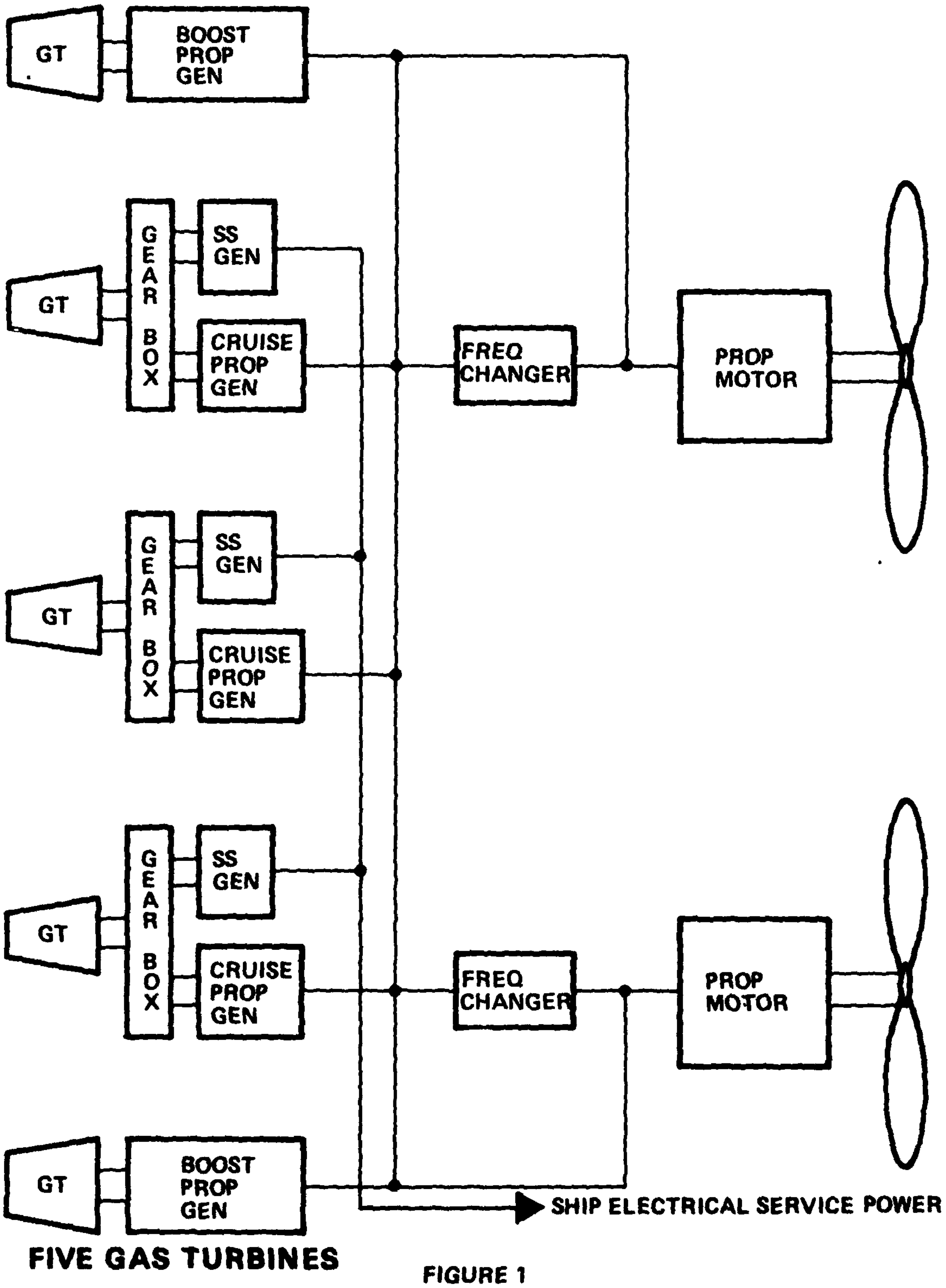
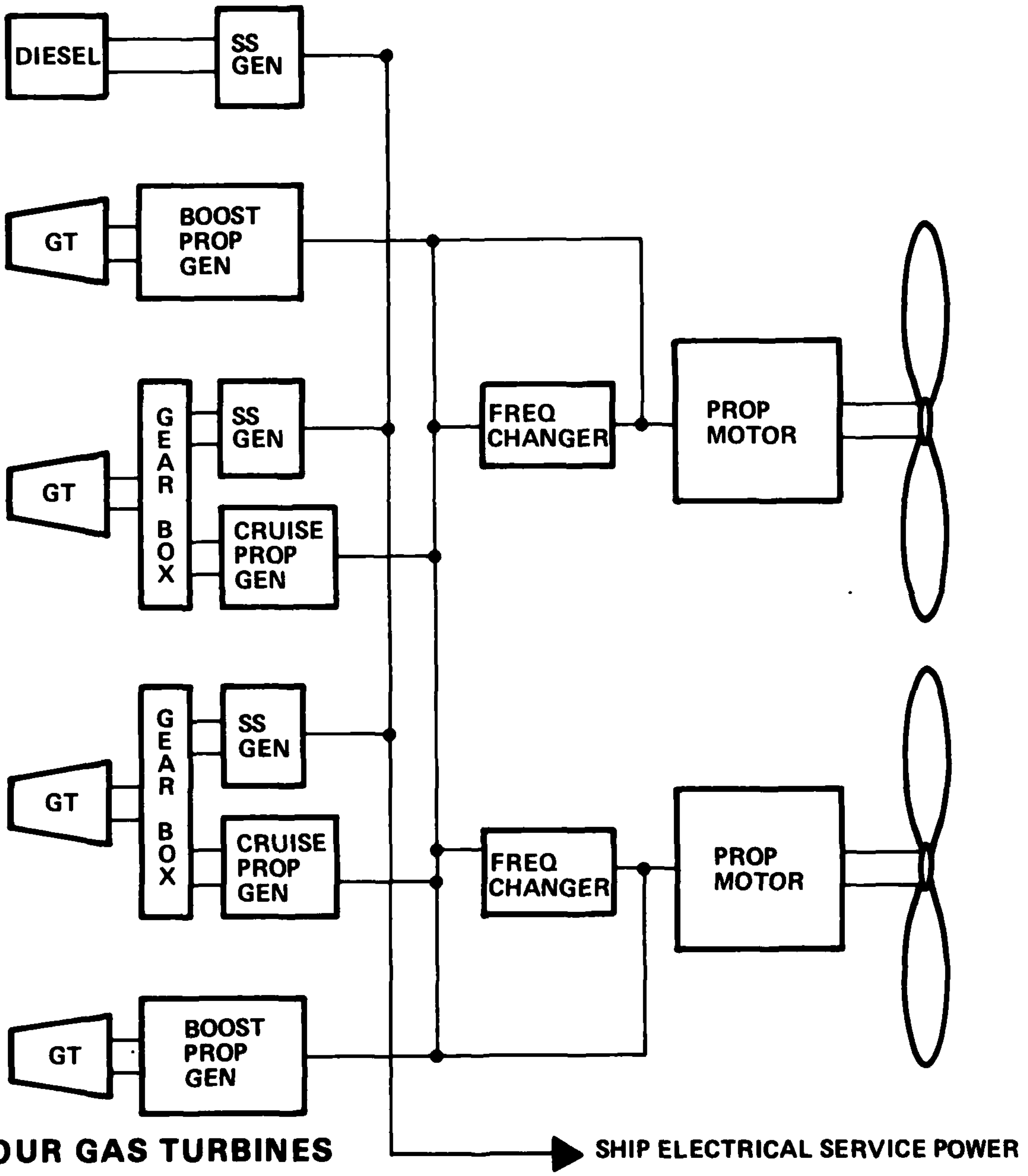


FIGURE 1

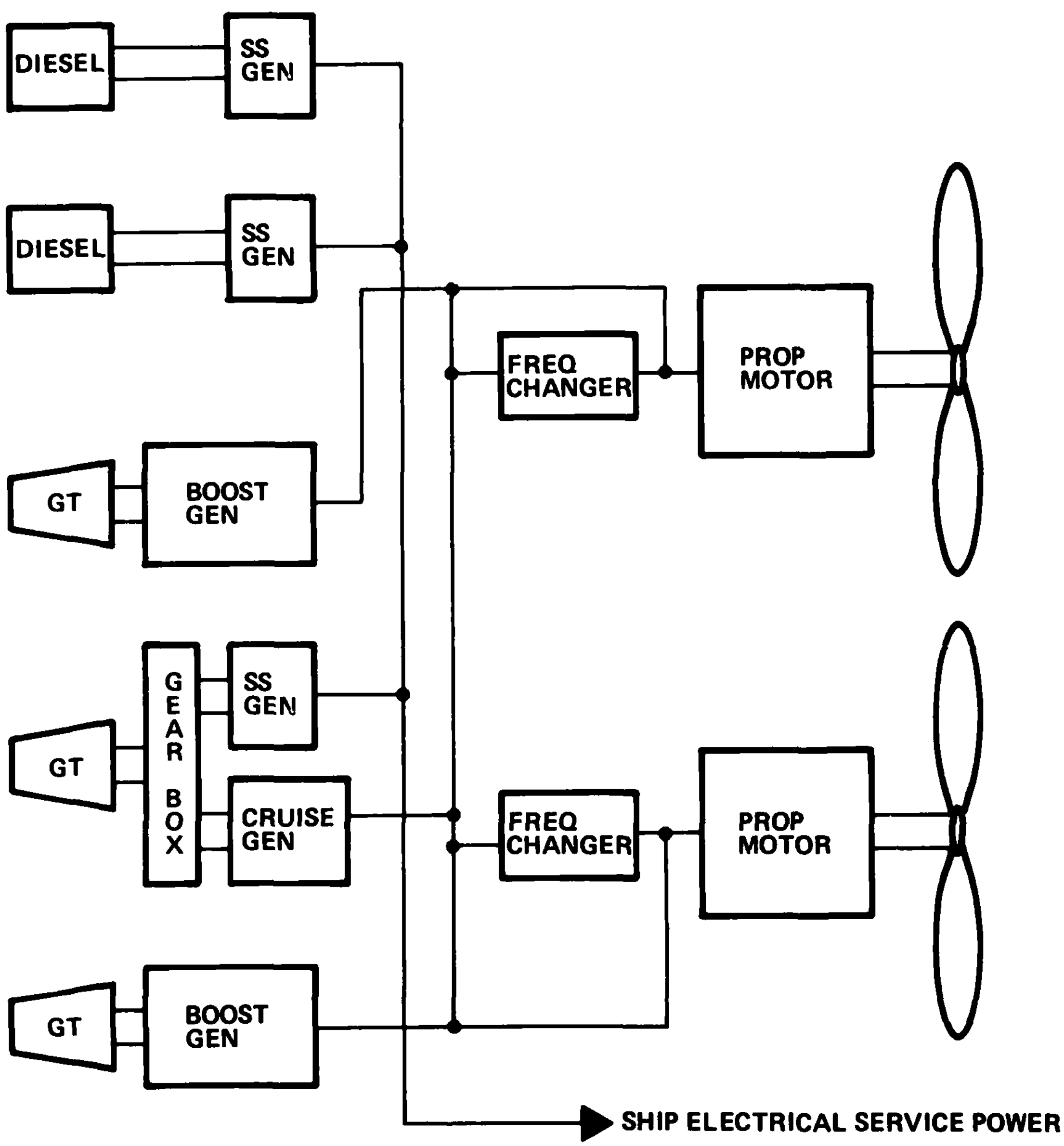
POWER FLOW DIAGRAM



FOUR GAS TURBINES
ONE DIESEL

FIGURE 2

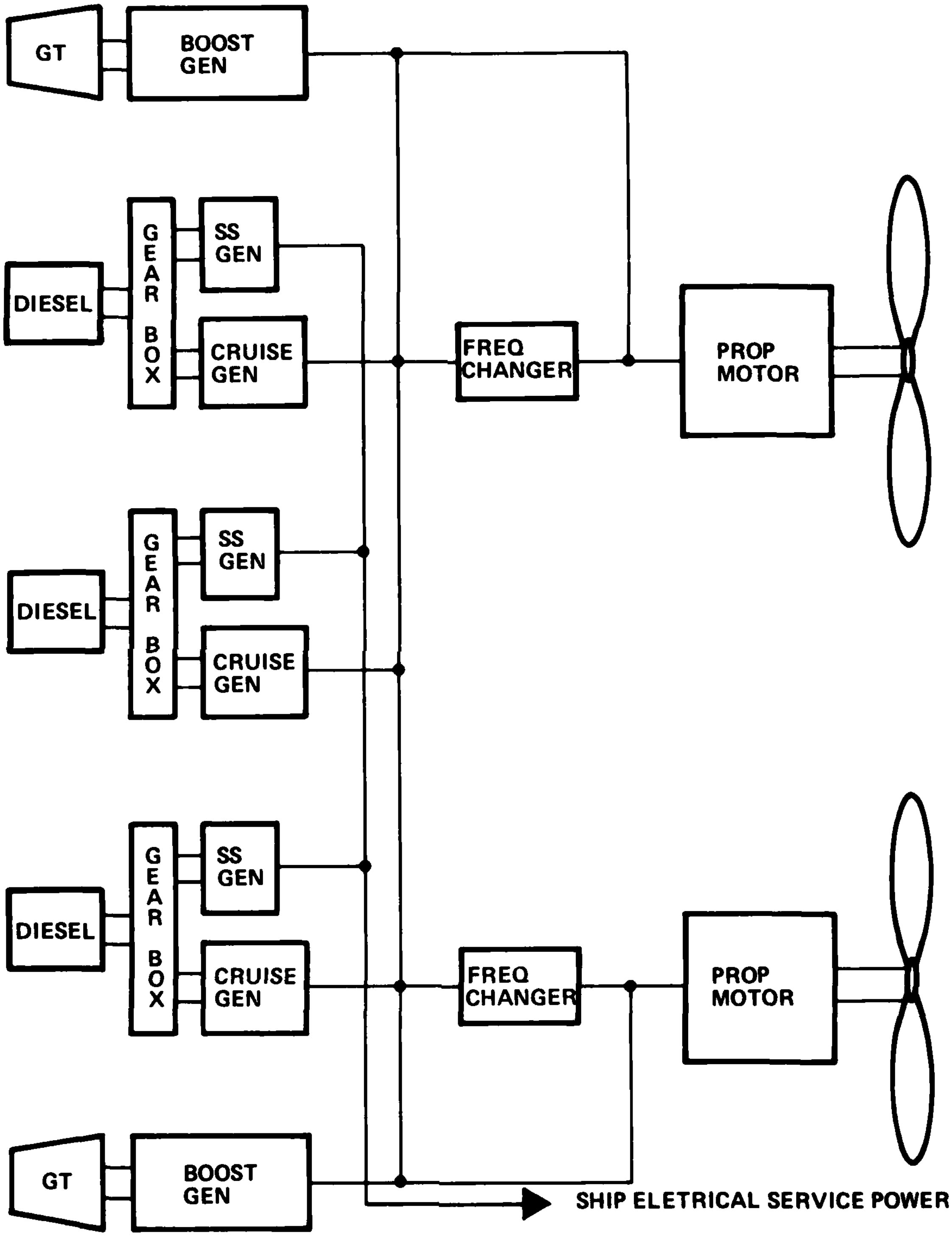
POWER FLOW DIAGRAM



THREE GAS TURBINES
TWO DIESELS

FIGURE 3

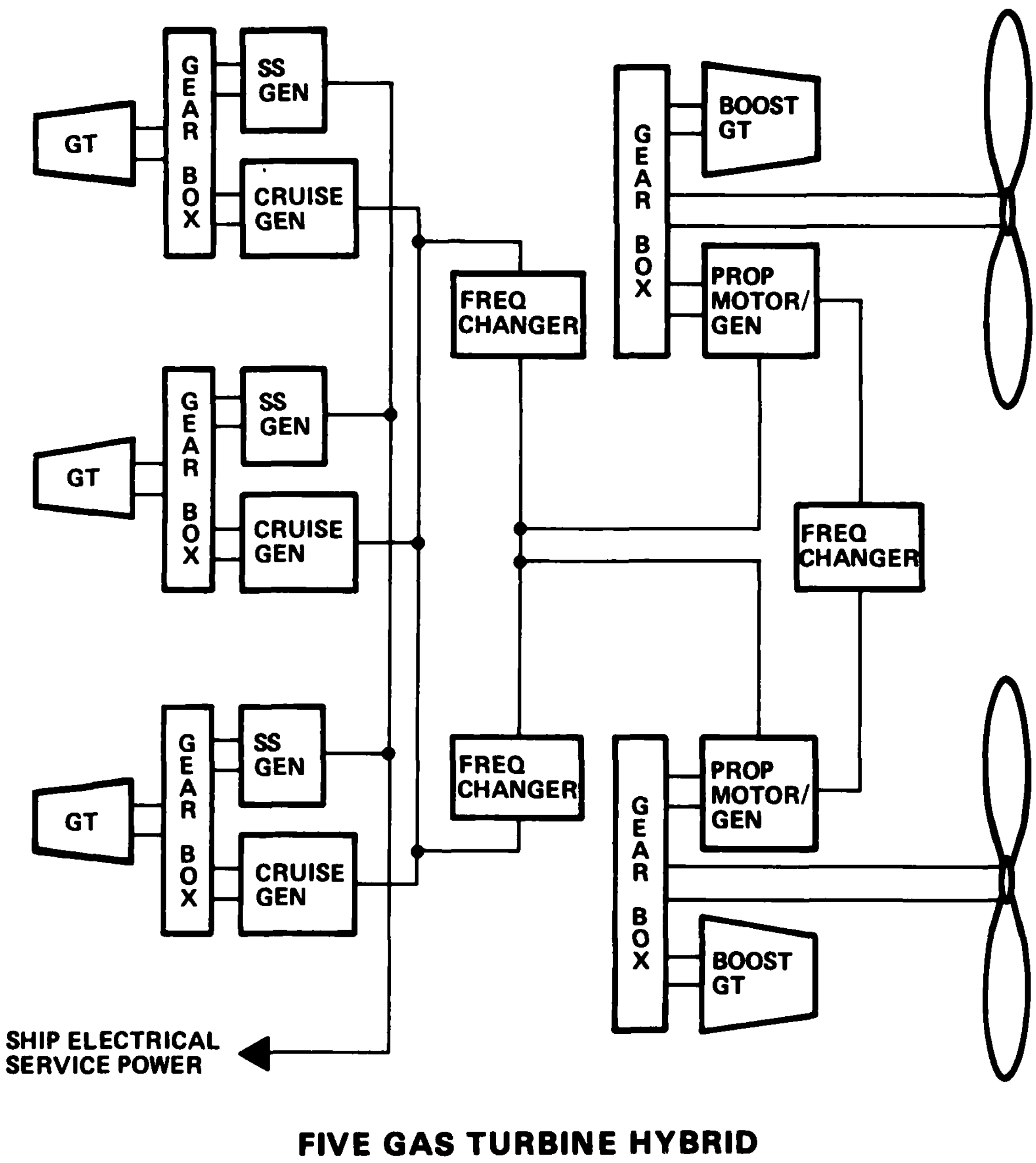
POWER FLOW DIAGRAM



TWO GAS TURBINES
THREE DIESELS

FIGURE 4

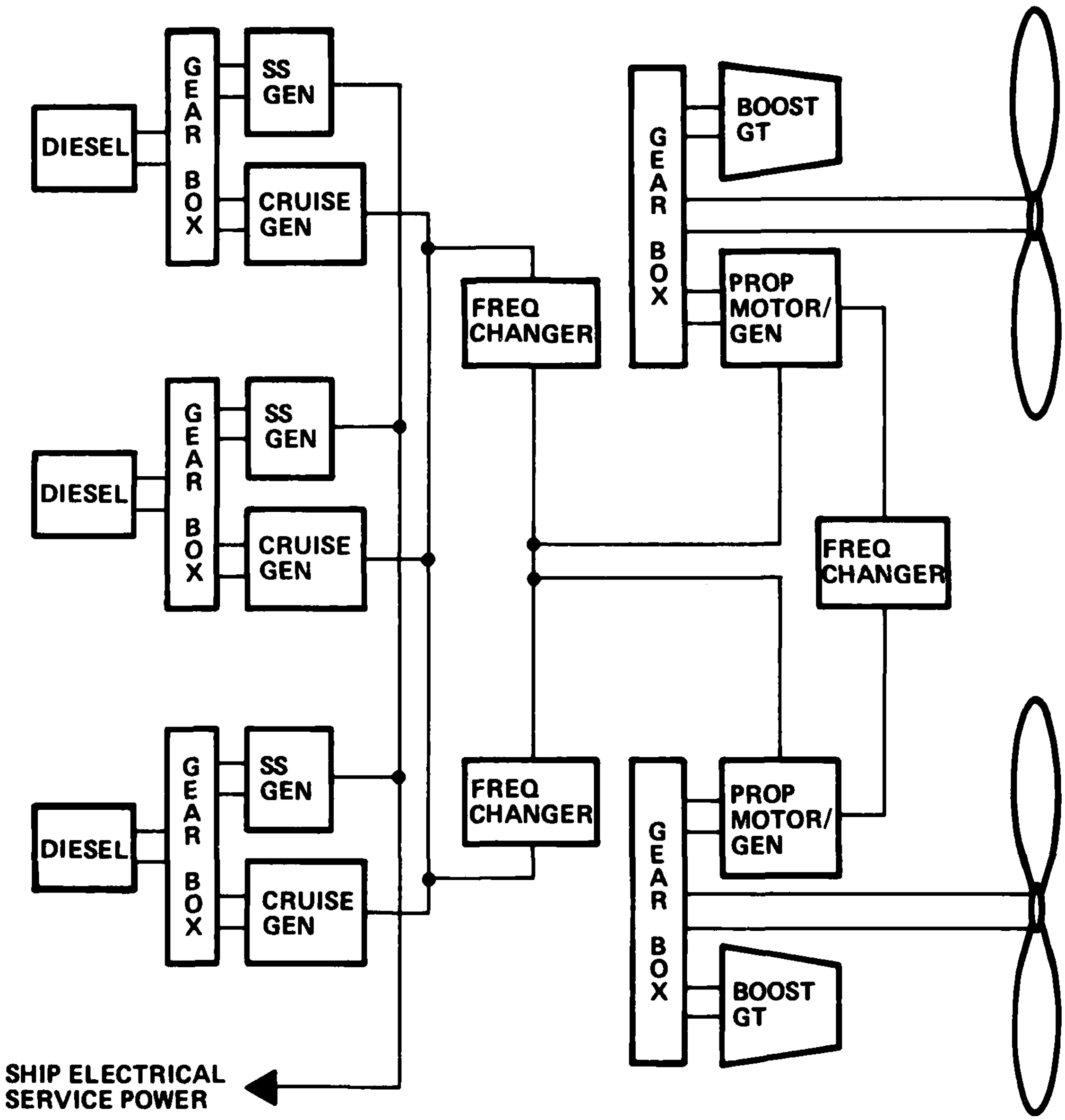
POWER FLOW DIAGRAM



FIVE GAS TURBINE HYBRID

FIGURE 5

POWER FLOW DIAGRAM



TWO GAS TURBINE HYBRID

FIGURE 6

INTEGRATED ELECTRICAL POWER GAS TURBINE MODULE

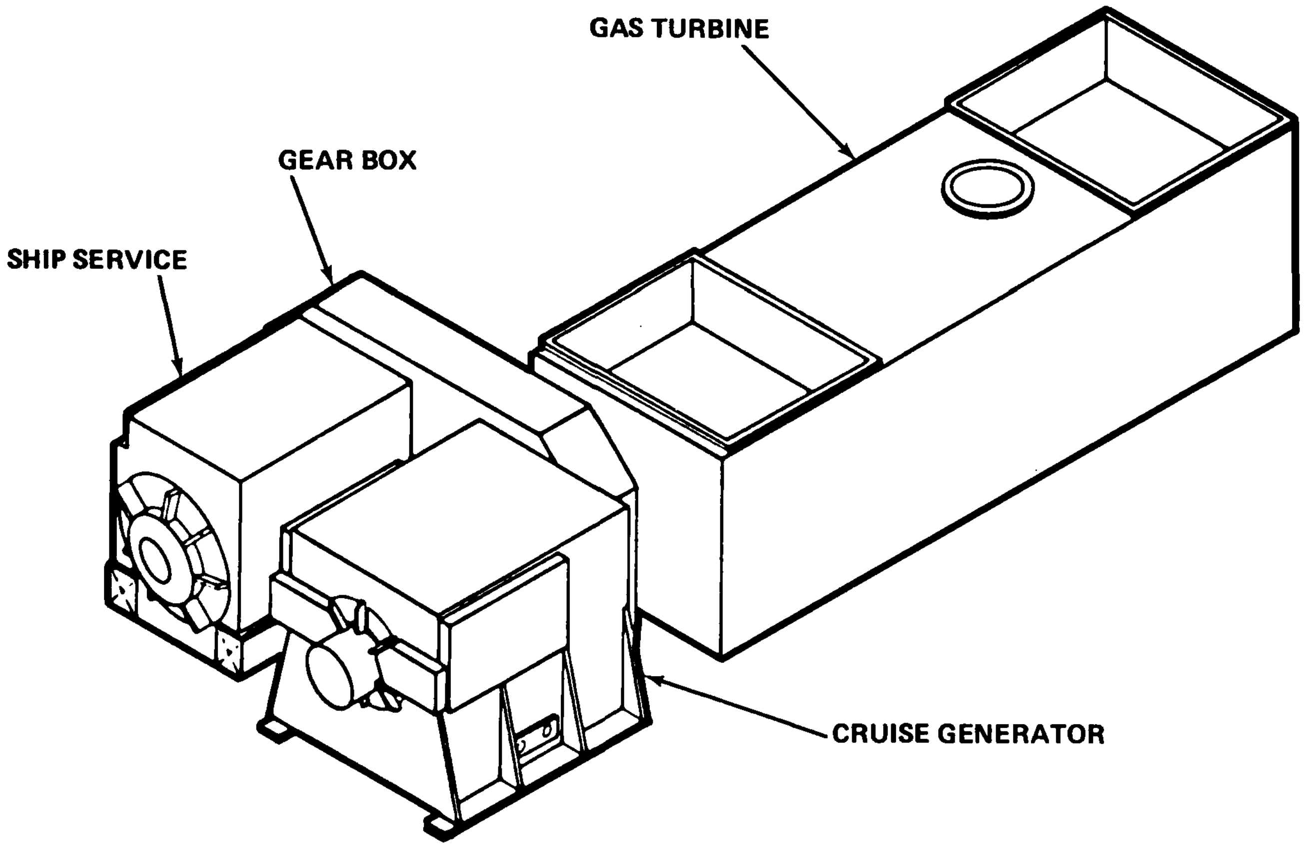


FIGURE 7

POWER FLOW DIAGRAM

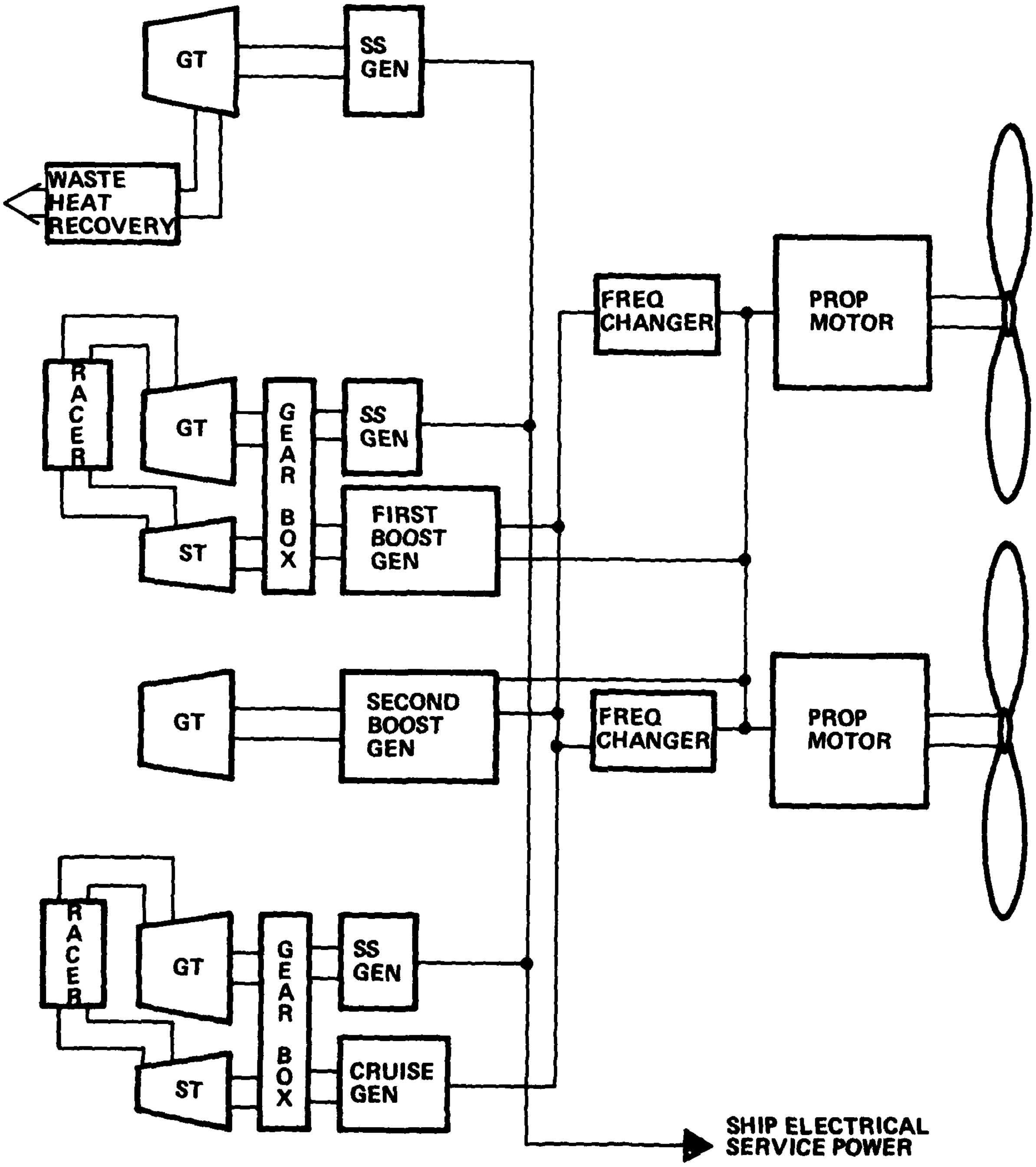


FIGURE 8

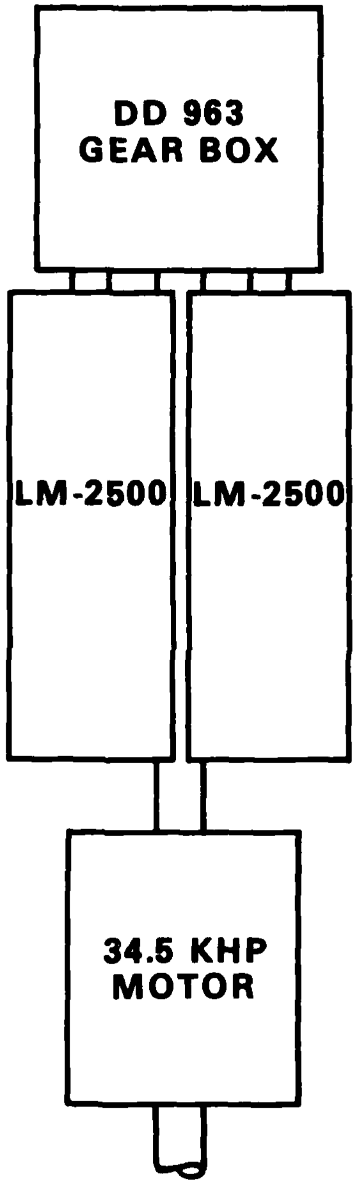


FIGURE 9. 70 KHP STARBOARD PROPULSION MODULE

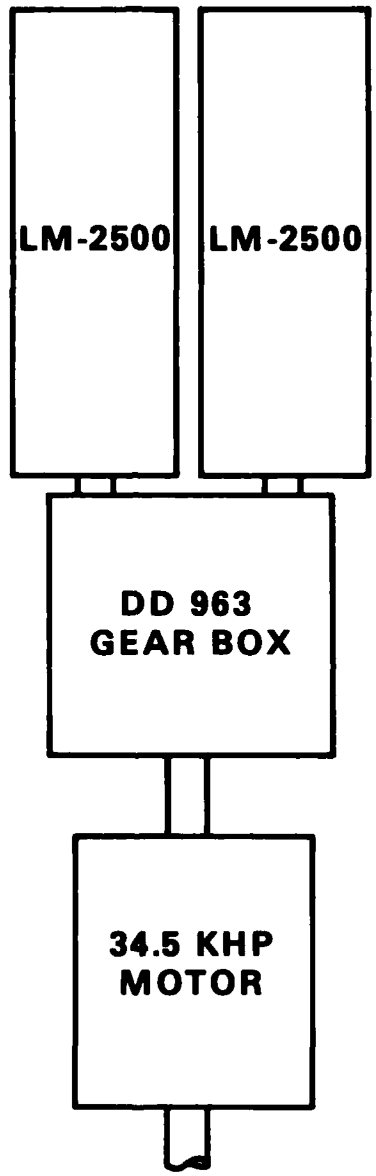


FIGURE 10. 70 KHP PORT PROPULSION MODULE

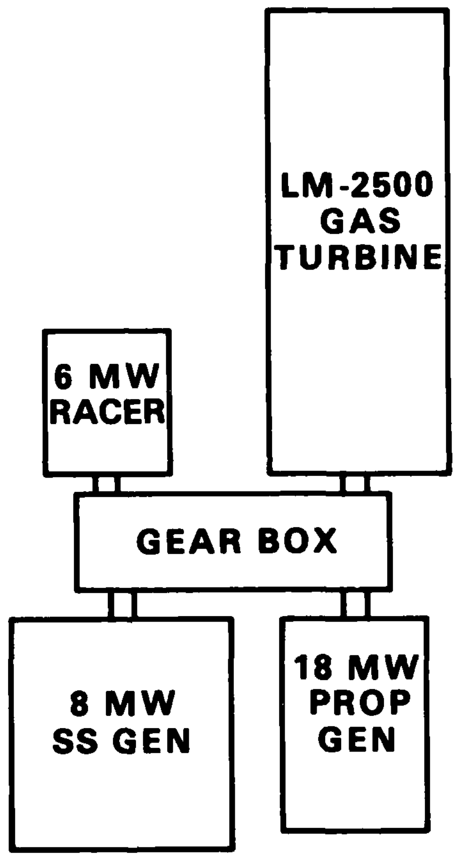


FIGURE 11. 50 KHP AND 70 KHP INTEGRATED ELECTRIC POWER MODULE

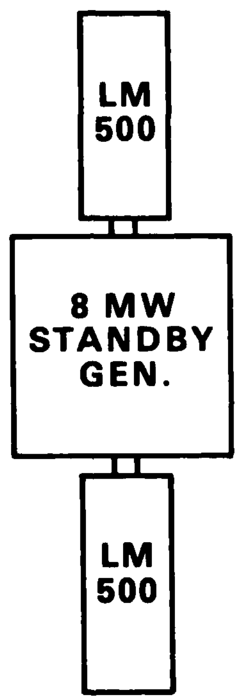


FIGURE 12. 50 KHP AND 70 KHP ELECTRIC POWER STANDBY MODULE

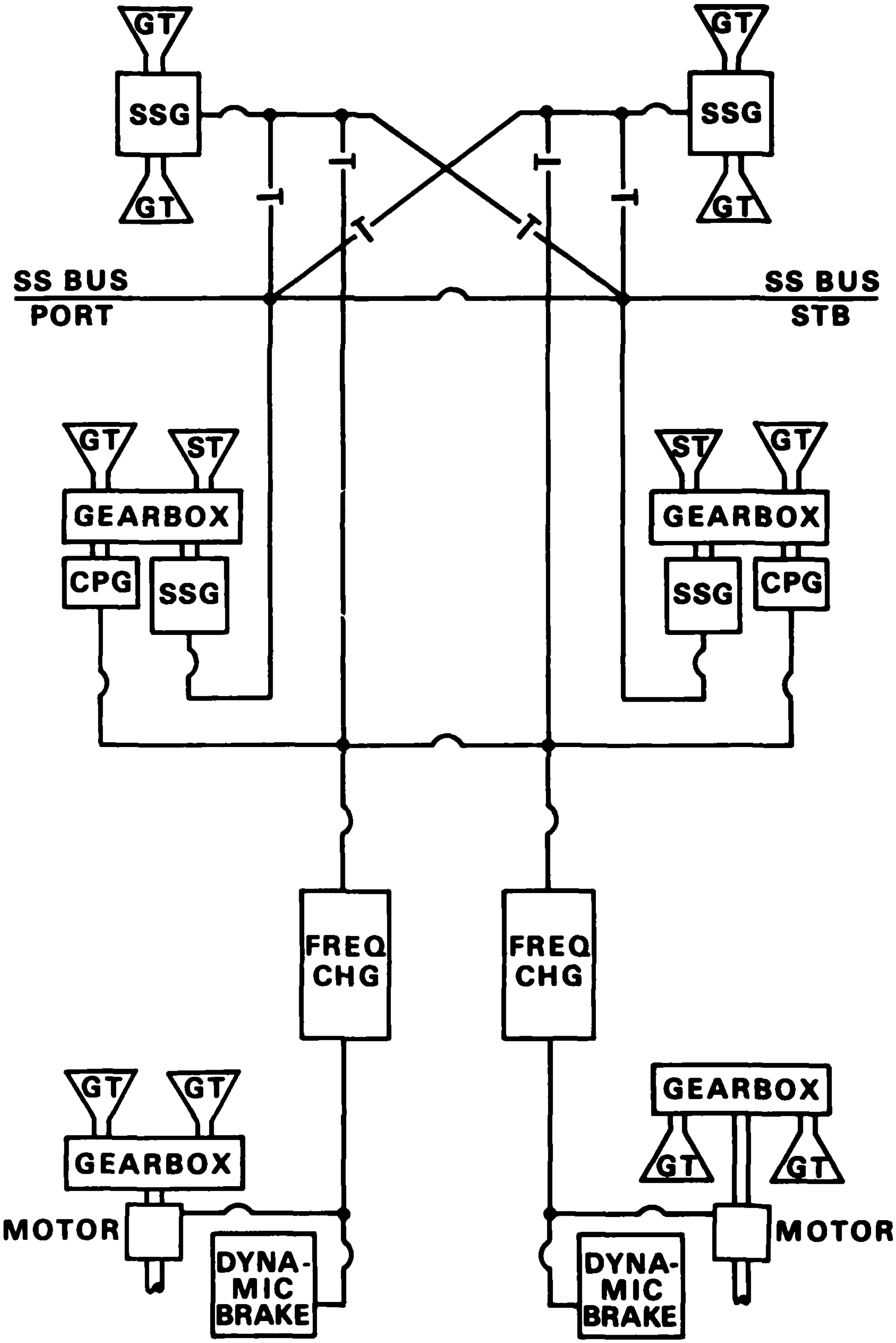


FIGURE 13. 70 KHP INTEGRATED ELECTRIC HYBRID PROPULSION PLANT ARRANGEMENT

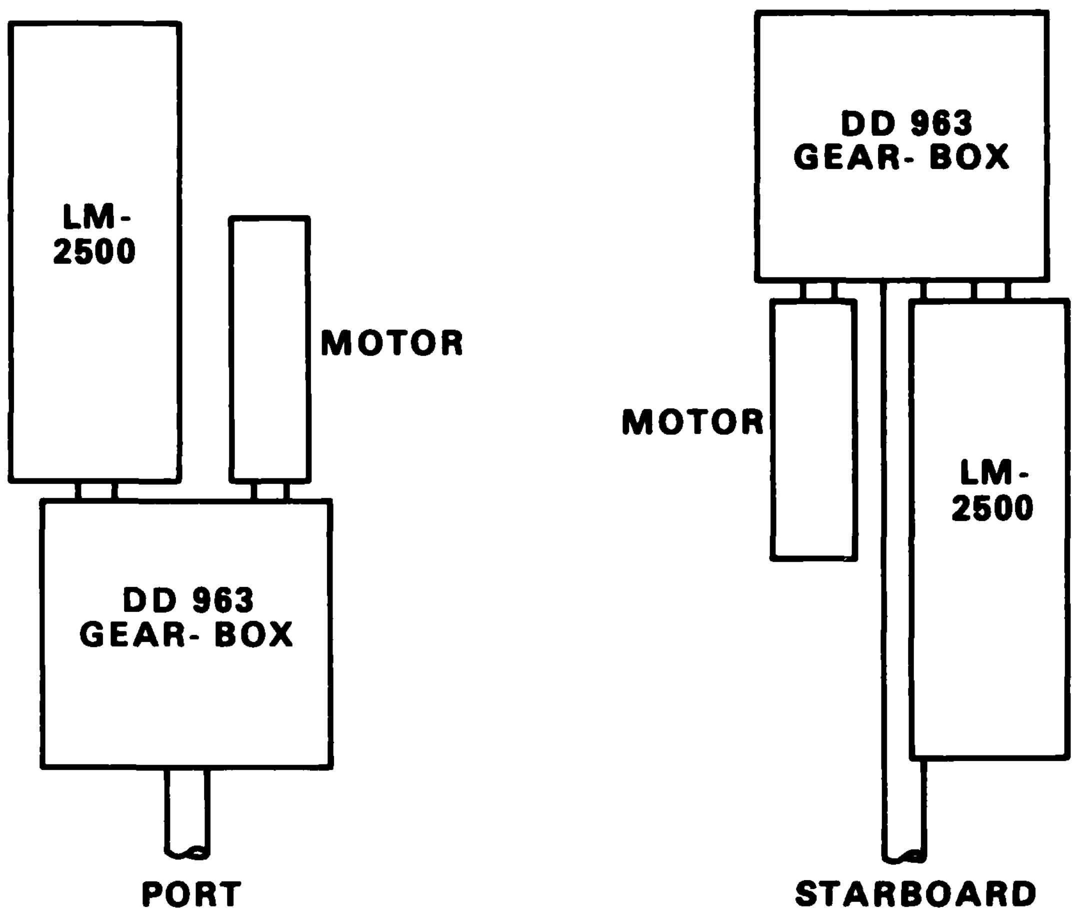


FIGURE 14. 50 KHP PROPULSION MODULES

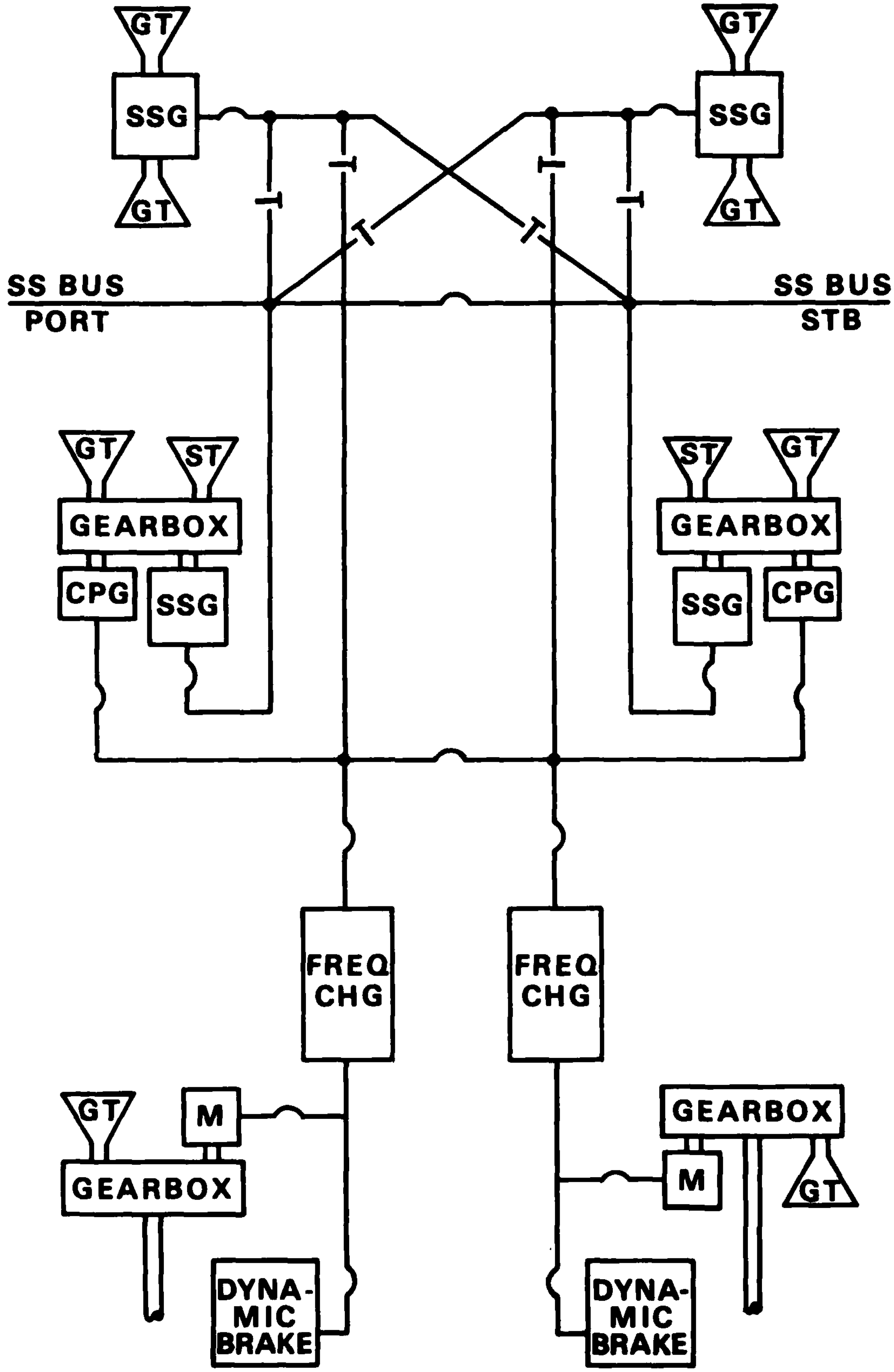


FIGURE 15. 50 KHP INTEGRATED ELECTRIC HYBRID PROPULSION PLANT ARRANGEMENT